SYNTHESIS OF SELECTIVE NOBLE NANOPARTICLES WITH REFERENCE TO GEOMETRIES AND THEIR POSSIBLE INFLUENCE ON EFFICACIES AGAINST MOSQUITOES OF PUBLIC HEALTH SIGNIFICANCE

A

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INTRODUCTION

Enormous growth in nanotechnology has opened up novel fundamentals in different streams such as nanoparasitology, nanobiotechnology, biotechnology, material science and engineering and applied microbiology etc. The nanoparticles have emerged as an important area of interest due to their very small size and differences in their physical and chemical properties such as biological, mechanical, sterical and optical properties etc. It is important in many areas such as mechanics, optics, chemical industry, electronics, space industries, drug-gene delivery, energy science, catalysis, photoeletrochemical applications, and nonlinear optical devices. Designing and making of materials with novel applications can be achieved by manipulating and exploiting their shape and sizes and also by altering their geometries.

Nanoparticles flaunt size and shape-dependent properties which are of interest in different fields. Applications are very wide ranging from biosensing and catalysts to optics, antimicrobial activity, computer transistors, electrometers, sensors which are chemical in nature. Nanoparticles generally are the particles with a size of up to 100 nm, which exhibit new or improved properties as compared to the larger particles of the bulk materials those are composed of based on specific characteristics such as size, distribution, and morphology.

The advancements in the formation of nanoscaled structures into earlier defined superstructures ensure that nanotechnology will definitely play a crucial role in many key technologies because the physical and biological characterstics are altered. Gold and silver nanoparticles are the most common noble metals used for biomedical applications and in emerging field of nanobiotechnology and also in vector control. Gold and Silver nanoparticles have drawn the attention of researchers because of their extensive applications. Nanoparticles demonstrate completely new or improved properties based on special characteristics such as size, morphology and distribution. In the field of medicine, gold nanoparticles are used for different

purposes. They are now widely used in the cancer treatment as it has been demonstrated that after cellular uptake, they can act as powerful thermal scalpels to kill cancer (Ferrari 2005).

Nanoparticles have been synthesised both physically and chemically for a long time, but recent developments show the critical use and exploitation of microorganisms and biological systems in production of metal nanoparticles. Over the past several years many biological sources like plants, algae, fungi, bacteria, and viruses have been used for low cost, energy-efficient, and nontoxic production of metallic nanoparticles. The use of organisms in this area is rapidly developing due to their growing success and ease of formation of nanoparticles. Biosynthesis of metal nanoparticles is an ecologically friendly method.

A very wide range of biological resources like microorganisms (bacteria, yeast, fungi, algae, and viruses) and plants can be used for nanoparticle synthesis . While microbased protocols have been developed from the cumulative research efforts of several authors, plant-derived biological synthesis of nanoparticles has gained attention only in the recent years. Currently, chemical and physical methods are mostly employed for nanoparticles synthesis at industrial level but use of toxic reducing agents for synthesis, very high temperature and pressure protocols, concerns for use in biomedical applications raise difficulties in utility of these methods. For instance, production of silver nanoparticles by chemical reduction may lead to absorption of harsh chemicals on the surfaces of nanoparticles raising the toxicity issue.

The organisms that are being used in nanoparticle synthesis vary from prokaryotic bacterial cells to complex eukaryotes. Gold nanoparticles are used for inducing apoptosis in B cell-chronic lymphocytic leukemia (chronic lymphoid leukemia. Silver nanoparticles have gained the importance of researchers because of their manifold applications in areas such as integrated circuits, sensors, biolabelling, filters, antimicrobial deodorant fibres, cell electrodes,and antimicrobials. Silver nanoparticles show potential antimicrobial effects against infectious organisms such as *Escherichia coli*, *Bacillus subtilis*, *Vibria cholera*, *Pseudomonas aeruginosa*,

Syphillis typhus, and *Staphylococcus aureus*.(Kouadio 2012). Nanoparticles have been produced physically and chemically. The capability of organisms in production of nanoparticles has opened a new exciting approach toward the development of these natural nano-factories.

The use of microorganisms such as bacteria, fungus and or macro organisms such as plant and algae can be suitable alternative method for nanoparticles These methods provide promotion over chemical and physical method as it is cost effective, environment friendly, easily scaled up for large scale synthesis and in these methods there is no need to use energy, high pressure, temperature and toxic chemical. Medical importance of mosquitoes vector for the transmission of serious diseases that cause death economical loss, and social disruption. Control of these diseases carrying vector is need of our as they are the major public health concern at global level. Once the person gets infected with malaria, then it involves typical medical treatment and there is report of resurgence of malaria after eradication in many countries.

The better strategy to lower the incidence of mosquito-transmitted diseases is to avoid biting of mosquito's using repellents and target larval stage of mosquito.Because, in larval stage they are having less mobility inbreeding habitat so devising control measures at this stage involves comparatively easy. Current practice to control mosquito larvae is the use of insecticides like organophosphate and pyrethroids. Insecticides in there early days of use exhibited success in reducing vector population but frequent and blind use of insecticides increased selection pressure on mosquitoes creating resistance to insecticides.

Varying resistance to commonly used insecticides like temephos, fenthion, malathion and dichlorodiphenyltrichloroethane (DDT) is reported by Tikar et al. 1997. Moreover, chemical insecticides associated with many concerns like harm to nontarget species long persistence in environment, entry in food chain . In view of these facts, insect control agents from biological sources can be considered as safe and effective substitute.

Over the past few decades, inorganic nanoparticles, whose structures show significantly new and improved physical, chemical, and biological properties, phenomena, and functionality due to their nanoscale size, have gained much interest. Nanophasic and nanostructured materials are attracting a great deal of attention because of their potential for achieving specific processes and selectivity, especially in biological and pharmaceutical applications. Discoveries in the past decade have illustrated that the electromagnetic, optical, and catalytic properties of noble-metal nanocrystals are strongly influenced by shape and size.(Kelly et al 2003).

This has prompted an upsurge in research on the synthesis methods that allow better control of shape and size, with projected applications in nanoelectronics and spectroscopy. Recent studies have demonstrated that specially formulated metal oxide nanoparticles have good antibacterial activity and antimicrobial formulations comprising nanoparticles could be effective bactericidal materials (Kumar et al. 2009)

Similarly in the present study the shape dependent properties of gold and silver nanoparticles with regard to the antimalarial properties will be investigated. Even different geometries of nanoparticles play significant role in the larvicidal properties of the nanometals. Elechiguerra and co-workers (2011) found that silver nanoparticles undergo a size-dependent interaction with human immunodeficiency virus type.

The interaction of silver nanoparticles with gram-negative bacteria has also been reported by the same group. However, little is known presently about how the biological activity of silver nanoparticles changes as the shape of the particles changes (Pal et al 2007).

Various physical and chemical parameters also play significant role in the change in the types of geometries of the synthesised nanoparticles and then their role in antimalarial aspect of the vector control. Different parameters like orientation of light, temperature and pH play important role in the formation of different geometries of nanoparticles and which particular geometry of nanoparticle is more effective in controlling the mosquito population will be investigated by this

study. The size-dependent antimicrobial activity of silver nanoparticles has already been investigated (Soni and Prakash 2015), so the size dependent and geometry dependent mosquito antilarval activity will be an entirely novel approach.

Researchers have used some complementary factors such as visible light or microwave irradiation, and boiling which could affect the size, morphology, and rate of reaction Saiffuddin et al (2009), Soni and Prakash (2011). Optimization of these crucial factors could control morphologies and other properties of nanoparticles. This exciting improvement toward the use of eco-friendly and economically viable methods for production of nanoparticles with morphological characteristics of desired shape and sizes might facilitate researcher's abilities to overcome many limitations of this field.

REVIEW OF LITERATURE

Nanotechnology has played the tremendous role in the field of vector control and environmental biology. Developments in the organization of nanoscaled structures into earlier defined superstructures ensure that nanotechnology will play a critical role in many key technologies. There are various methods of synthesis of nanoparticles for different applications and they have been proved very effective. Many synthesised nanoparticles are having larvicidal efficacy against some mosquito species and considerable work has been done in this domain. Borase *et al* (2013) investigated that biosynthesized silver nanoparticles are novel biolarvicidal agent and can be used along with traditional insecticides as approach of Integrated Pest Management (IPM). His investigation showed that the synthesized AgNPs from different plant tissues show environmental friendly larvicidal activity. Therefore, plant extracts from under this study can be promising candidates for synthesis of mosquito larvicidal nanoparticles

Many methods have been employed for the synthesis of metal nanoparticles and various organisms have been used this purpose and they have been proved very effective for the vector control approach. Nanoparticles have been produced by different methods for a long time, but recent developments show the effective role of microorganisms and biological systems in production of metal nanoparticles. Biosynthesis of metal nanoparticles is an eco friendly method without use of harsh, toxic and expensive chemicals. Kamalkannan et al (2014) investigated the larvicidal activities of mycosynthesized silver nano-particles (AgNPs) against filarial vector, *Cx. quinquefasciatus*. The AgNPs were synthesized by filamentous fungus *Penecillium verucosum*, characterized by UV-Visual spectrophotometer and many other microscopic techniques.

In recent years, the development of efficient green chemistry methods for synthesis of metal nanoparticles has become a major centre of attention of researchers. They have investigated in order to find an eco-friendly technique for production of well-characterized nanoparticles. Rad Sharifi *et al* (2013). In their study used the *extracts* of dry fruit for biological synthesis of gold and silver nanoparticles as a reducing agent then size and morphology of these nanoparticles was determined by electronic microscope to study the different geometries of these nanoparticles.

Many other prominent and effective methods of synthesis of nanoparticles have been derived. Iravani (2011) in his work investigated the advantages of using plant and plant mediated materials for biosynthesis of metal nanoparticles that have interested researchers to study mechanisms of metal ions uptake and bioreduction by plants, and to understand the possible mechanism of metal nanoparticle formation in plants.

A very wide range of biological resources like microorganisms (bacteria, yeast, fungi, algae, and viruses) and plants can be used for nanoparticle synthesis. Plant extracts reduce the metal ions in a shorter time as compared to microbes. Herlekar *et al* (2014) in their study outlined the novel routes for biosynthesis of these nanoparticles by plant resources along with outlining the future scope of work in this area.

The development of rapid and reliable processes for the synthesis of nanosized materials is of great importance in the field of nanotechnology considerable work has been done under this regard. Saifuddin *et al* (2008) in his work described the the synthesis of metallic nanostructures of noble metals such as silver (Ag), by using a combination of culture residues of *Bacillus subtilis* and microwave (MW) irradiation in water in absence of a surfactant or soft template. Although many synthetic technologies are well documented, the search for suitable biomaterials for the synthesis of nanoparticles is popular among the researchers all around the world.

Daniel *et al* (2011) in his study discussed the biosynthesis of Silver nanoparticles using the *Achyrathus aspera* plant extract that throws light on the biocompatible methods of synthesis that encourages its use of these nano particles in human system using Zebra fish model with an aim of possible formulations of using silver nanoparticles in desired drug delivery.

Attempts to develop novel materials as mosquito larvicides are necessary. With the progress of nano-technology, many laboratories around the world have investigated silver nanoparticles (AgNPs) production as the nanoparticle possesses more surface atoms than a microparticle, which greatly improves the particle's physical and chemical characteristics. Many biological methods have been employed to synthesise novel metal nanoparticles. Many microbes have also been used for the extraction of the metal nanoparticles .Prakash and Soni (2012) in their studies suggested that the use of AuNPs synthesized by fungus was a more rapid and eco friendly approach for mosquito control than present day approaches

Does the antilarval activity of silver nanoparticles depend on the shape and different geometries of the Nanoparticle? Our laboratory has been actively participating in the novel areas of nanoparasitology which involves the different biological methods of synthesis of nanoparticles with biological sources like microbes and plant extracts. Prakash and Soni (2011) in their work explored the possibilities to manipulating the geometry of silver nanoparticles by changing the key growth parameters such as pH, temperature, concentrations and time. The effect of AgNO3 with the cell free extract of fungi and time, temperature, pH with the formation of silver has also been investigated. The presence of nanosilver has been carried out with the Micro-scan reader and has been confirmed by X-Rays Diffractometer (XRD).There are publications in our laboratory regarding the efficacies of different Nanogold and Nanosilver for controlling the mosquito populations.(2011,2012,2013,2014).

Pal *et al* (2006) investigated the antibacterial properties of different shaped silver nanoparticles against the gram-negative bacterium *Escherichia coli*, both in liquid systems and on agar plates

and results of the work demonstrated that silver nanoparticles undergo a shape-dependent interaction with the gram-negative organism *E. coli*. This showed that the shape of the nanoparticle play a very crucial role in its efficacy, hence this property and differences in the geometries can be exploited to investigate whether the mosquito larval efficacy of the nanoparticles is changed with their respective geometries.

In their study Soni and Prakash (2015) have tested for the antibacterial effect against the gram positive bacteria *Bacillus subtilis and Bacillus thuringiensis* and was inferred that effective nanobiomaterial for vector control and antibacterial agent can be developed.

These different shapes, size and geometries of nanoparticles can be used in the field of mosquito control, medicine and diseases diagnosis. These can be used efficiently in the field of vector control biotechnology which is a new approach and environment friendly too.

The size-dependent antimicrobial activity of silver nanoparticles has been investigated however the role of geometry based mosquitocidal activity of gold and silver nanoparticle is a novel approach in the field of mosquito control as we can exploit these properties which can be very cost effective and environmental friendly for future mosquito control and significant for public health concern.

OBJECTIVES

1. Synthesis of gold and silver nanoparticles with different methods i.e. biological and chemical.

2. To test and validate the efficacy of the newly synthesised metal nanoparticles on different vector mosquito populations.

3. To investigate minutely the role of different geometries on their properties against selected vector mosquito populations.

4. To study the potential role of different physical parameters on the synthesis and on the efficacies of the nanoparticles in laboratory.

5. To integrate and validate all these technologies in the area of mosquito control which could be species specific.

METHODS AND MATERIALS

To achieve the mentioned objectives of synthesis and characterisation of the metal nanoparticles with respect to their geometries and efficacies, the following methodologies would be used for the requirements of the objectives defined..

METHODOLOGY AND PROTOCOL

A. Synthesis of the noble nanoparticles: To synthesise the gold and silver nanoparticles, different biological and chemical methods will be employed.

i. **Biological Methods: -** The biological methods for the synthesis of the nanoparticles includes synthesis from fungal strains, bacteria etc. Different plant tissues will be used for the nanoparticles which is a very effective eco friendly method.

Reduction of aqueous Ag+ and $AuCl_4$:- Synthesis of bimetallic core-shell nanoparticles of gold and silver by simultaneous reduction of aqueous Ag+ and $AuCl_4$ ions with the broth of selected plant extracts.

ii. **Chemical methods: -** Cellulosic materials will also be used to synthesize and stabilize metal nanoparticle.

- Chemical reduction of salts.
- Photochemical reduction of Au compounds.
- Thermal decomposition of silver oxalate in water and Ethylene glycol.

B. Characterisation of synthesised nanoparticles for determining their geometries and effect of physical parameters on them :-

For the characterisation of shape and geometries of metal nanoparticles different techniques will be employed like:-

- UV-Vis Spectroscopy: - To determine the presence of nanoparticles in the solution.
- FT-IR Analysis:- To visualise the structure and respective bands of the synthesised nanoparticles.
- Scanning Electron Microscope (SEM) :- To determine the size and morphology of the nanoparticles.
- X Ray Diffraction Analysis :- To know the crystal structure and the crystallite size.
- Atomic Force Microscopy :- Characterization of variable geometry nanoparticles.

C. Materials for study:-

Plant extracts- Plant extracts of plants like *Aloe barbendensis (aloe vera)* (Burm F.) , *Azardiracta indica* (neem) (A.Juss) , *Ficus religiosa* (peepal) (L.) leaf extracts will be used for synthesis of gold and silver nanoparticles.

Vector species scheduled-Larval/adult stages of vector mosquito populations like *Culex quinquifasciatus* (Say) / *Anopheles stephensi* (Liston) / *Aedes aegypti* (Linnaeus) will be used for testing the efficacy of the synthesised metal nanoparticles.

Larval/ Adult mortality assessment

Statistical Analysis:-Due to changing geometries and physical parameters Probit analysis will be used for determination of LC_{50}, LC_{90} and LC_{99} data from mortality and effect of concentrations will be subjected to analysis of variance.

REFERENCES

- Abhilash, K. Revati, and Pandey B.D. ,(2011) "Microbial synthesis of iron-based nanomaterials—a review," *Bulletin of Materials Science*, vol. 34, no. 2, pp. 191–198,
- Beveridge, T.J., M.N. Hughes, H. Lee, K.T. Leung and R.K. Poole *et al*., (1997). Metal-microbe interactions: Contemporary approaches. Adv.Microbial. Physiol., 38: 177-243. DOI: 10.1016/S0065-2911(08)60158-7
- Borase Hemant P, Patil Chandrashekhar D , Salunkhe B , Chandrakant P.(2013) "Phyto-Synthesized Silver Nanoparticles: A Potent Mosquito Biolarvicidal Agent" J Nanomedine Biotherapeutic Discov 3:1
- Callegari, A., D. Tonti, and M. Chergui**.(** 2003). Photochemically grown silver nanoparticles with wavelength-controlled size and shape. Nano Lett. **3:**1565–1568.
- Daniel, S. K., Ayyappan, S., Philiphan, N. J. P., Sivakumar, M., Menaga, G., & Sironmani, T. A. (2011). Green Synthesis and Transfer of Silver Nanoparticles in a Food Chain through Chiranamous Larva to Zebra Fish-A New Approach for Therapeutics. *International Journal of Nanoscience and Nanotechnology*, *2*, 159-169.
- Gericke, M. and A. Pinches, (2006) . Microbial production of gold nanoparticle. Gold Bull., 39:22-28. DOI: 10.1007/BF03215529
- Gardea-Torresdey JL, Parsons JG, Gomez E, Peralta-Videa J, Troiani HE, Santiago P,Jose- Yacaman M. (2009) Formation and growth of Au nanoparticles inside live *Alfalfa* plants. *Nano Letters*.; 2: 397-401,
- Herlekar, M., Barve, S., & Kumar, R. (2014). Plant-Mediated Green Synthesis of Iron Nanoparticles. *Journal of Nanoparticles*,
- Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green Chemistry*, *13*(10), 2638-2650.
- J. L. Gardea-Torresdey, J. G. Parsons, E. Gomez et al. (2012), "Formation and growth of Au nanoparticles inside live Alfalfa plants," *Nano Letters*, vol. 2, no. 4, pp. 397–401

- Kamalakannan, S., Gobinath, C., & Ananth, S. (2014). Synthesis and Characterization of Fungus Mediated Silver Nanoparticle for Toxicity on Filarial Vector, Culex quinquefasciatus. *International Journal of Pharmaceutical Sciences Review & Research*, *24*(2).
- Kemp MM, Kumar A, Mousa S, Dyskin E, Yalcin M, et al. (2009) Gold and silver nanoparticles conjugated with heparin derivative possess anti-angiogenesis properties. Nanotechnology 20: 455104
- Kumar M, Sneha K, Won SW, Cho CW, Kim S, Yun YS, (2009) *Cinnamon zeylanicum* bark extract and powder mediated green synthesis of nano-crystalline silver particles and its bactericidal activity, Colloids Surf B: Biointerfaces, 73,332–338.
- Kumar S, Abyaneh MK, Gosavi SW, Kulkarni SK, Pasricha R, et al. (2007) Nitrate reductase-mediated synthesis of silver nanoparticles from AgNO3. Biotechnol Lett 29: 439-445.
- Loo YY, Chieng BW, Nishibuchi M, Radu S (2012) Synthesis of silver nanoparticles by using tea leaf extract from Camellia sinensis. Int J Nanomedicine 7: 4263-4267.
- Marimuthu S, Rahuman AA, Rajakumar G, Santhoshkumar T, Kirthi AV, et al. (2011) Evaluation of green synthesized silver nanoparticles against parasites. Parasitol Res 108: 1541-1549.
- Mulvaney, P**. (**1996). Surface plasmon spectroscopy of nanosized metal particles. Langmuir 12**:**788–800.
- Naik RR, Stringer SJ, Agarwal G, Jones SE, Stone MO (2002) Biometric synthesis and patterning of silver nanoparticles. Nat Mater 1: 169-172.
- P. Mohanpuria, N. K. Rana, and S. K. Yadav, (2008) "Biosynthesis of nanoparticles: technological concepts and future applications,"*Journal of Nanoparticle Research*, vol. 10,no. 3, pp. 507–517,

- Pal, S., Tak, Y. K., & Song, J. M. (2007). Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium Escherichia coli. *Applied and environmental microbiology*,*73*(6), 1712-1720.
- Panaceka A, Milan K, Renata V, Robert P, Jana S, Vladimır K, Petr H, Radek Z, Libor K, (2009) Antifungal activity of silver nanoparticles against Candida spp., Biomaterials, 30, 6333–6340.
- Parashar UK, Saxena SP, Srivastava A. Bio inspired synthesis of silver nanoparticles. *Dig. J. Nanomater Bios.*; 4(1): 159- 166,2009
- Patil CD, Patil SV, Borase HP, Salunke BK, Salunkhe RB (2012) Larvicidal activity of silver nanoparticles synthesized using Plumeria rubra plant latex against Aedes aegypti and Anopheles stephensi. Parasitol Res 110: 1815-1822.
- Patil SV, Borase HP, Patil CD, Salunke BK (2012) Biosynthesis of silver nanoparticles using latex from few Euphorbian plants and their antimicrobial potential. Appl Biochem Biotechnol 167: 776-790.
- P. Mohanpuria, N. K. Rana, and S. K. Yadav, "Biosynthesis of nanoparticles: technological concepts and future applications,"*Journal of Nanoparticle Research*, vol. 10,no. 3, pp. 507–517, 2008.
- Priyadarshini KA, Murugan K, Panneerselvam C, Ponarulselvam S, Hwang JS, et al. (2012) Biolarvicidal and pupicidal potential of silver nanoparticles synthesized using Euphorbia hirta against Anopheles stephensi Liston (Diptera:Culicidae). Parasitol Res 111:997-1006
- Rad, Majid Sharifi, et al.(2013) "Biological synthesis of gold and silver nanoparticles by Nitraria schoberi fruits." *American Journal of Advanced Drug Delivery* 2 (2013): 174-179.
- Saifuddin, N., Wong, C. W., & Yasumira, A. A. (2009). Rapid biosynthesis of silver nanoparticles using culture supernatant of bacteria with microwave irradiation. *Journal of Chemistry*, *6*(1), 61-70.

- Shaalan EA, Canyon D, Younes MW, Abdel-Wahab H, Mansour AH (2005) A review of botanical phytochemicals with mosquitocidal potential. Environ Int 31: 1149-1166.
- Santhoshkumar T, Rahuman AA, Rajakumar G, Marimuthu S, Bagavan A, et al. (2011) Synthesis of silver nanoparticles using Nelumbo nucifera leaf extract and its larvicidal activity against malaria and filariasis vectors. Parasitol Res 108: 693-702.
- Sarkar R, Kumbhakar P, Mitra AK, (2012) Green synthesis of silver nanoparticles and its optical properties, Dig J Nanomater Bios, 5, 491-496.
- Saifuddin N, Wong CW, Yasimura (2009) Rapid biosynthesis of silver nanoparticles using culture supernatant of bacteria with microwave irradiation. *E- J. Chem*.; 6(1): 61-70,
- S. C. G. Kiruba Daniel, G. Vinothini, N. Subramanian, K.Nehru, and M. Sivakumar, "Biosynthesis of Cu, ZVI, and Ag nanoparticles using *Dodonaea viscosa* extract for antibacterial activity against human pathogens," *Journal of Nanoparticle Research*, vol. 15, no. 1, article 1319, 2013.
- Soni, N., & Prakash, S. (2012a). Efficacy of fungus mediated silver and gold nanoparticles against Aedes aegypti larvae. *Parasitology research*, *110*(1), 175-184.
- Soni, N., & Prakash, S. (2012b) Factors affecting the geometry of silver nanoparticles synthesis in Chrysosporium tropicum and Fusarium oxysporum.*American Journal of Nanotechnology*, *2*(1), 112.
- Soni, N., & Prakash, S. (2012c). Factors affecting the geometry of silver nanoparticles synthesis in Chrysosporium tropicum and Fusarium oxysporum.*American Journal of Nanotechnology*, *2*(1), 112.
- Soni, N., & Prakash, S. (2012d) Fungal-mediated nano silver: an effective adulticide against mosquito. *Parasitology research*, *111*(5), 2091-2098.
- Soni, N., & Prakash, S. (2012e) Synthesis of gold nanoparticles by the fungus Aspergillus niger and its efficacy against mosquito larvae. *Rep Parasitol*, 2, 1-7

- Soni, N., & Prakash, S. (2013a). Possible mosquito control by silver nanoparticles synthesized by soil fungus (Aspergillus niger 2587).
- Soni, N., & Prakash, S. (2013b). Silver Nanoparticles Embedded Fungal Metabolites Against Culex quinquefasciatus. *Advanced Science, Engineering and Medicine*, *5*(11), 1150-1156.
- Soni, N., & Prakash, S. (2014). Silver nanoparticles: a possibility for malarial and filarial vector control technology. *Parasitology research*, *113*(11), 4015-4022.
- Sosenkova LS, Egorova EM (2011) The effect of particle size on the toxic action of silver nanoparticles. III Nanotechnology International Forum. Journal of Physics: Conference Series 291: 012027.
- S. Venkateswarlu, Y. S. Rao, T. Balaji, B. Prathima, and N. V. V. Jyothi, (2013) "Biogenic synthesis of Fe3O4 magnetic nanoparticles using plantain peel extract," *Materials Letters*, vol. 100, pp. 241– 244, .
- T.Wang, X. Jin, Z. Chen, M. Megharaj, and R. Naidu, (2014) "Green synthesis of Fe nanoparticles using eucalyptus leaf extracts for treatment of eutrophic wastewater," *Science of the Total Environment*, vol. 466-467, pp. 210–213,
- V. Bansal, D. Rautaray, A. Ahmad, and Sastry M, (2004) "Biosynthesis of zirconia nanoparticles using the fungus *Fusarium oxysporum*," *Journal of Materials Chemistry*, vol. 14, no. 22, pp. 3303–3305.
- Vigneshwaran N, Ashtaputre NM, Varadarajan PV, Nachane RP, Paralikar KM, Balasubramanya RH, (2007) Biological synthesis of silver nanoparticles using the fungus *Aspergillus flavus*, Mater Lett, 61, 1413
- W. Wu, Q. He, and C. Jiang, (2008) "Magnetic iron oxide nanoparticles: synthesis and surface functionalization strategies," *Nanoscale Research Letters*, vol. 3, no. 11, pp. 397–415,

- White II GV, Kerschersss P, Brown RM, Morella JD, McAllister W, et al. (2012) Green synthesis of robust, biocompatible silver nanoparticles using garlic extract. J Nanomater

***The recent work of our laboratory for nanoparticle based mosquito control:-

- Soni, N., & Prakash, S. (2014a). Silver nanoparticles: a possibility for malarial and filarial vector control technology. *Parasitology research*, *113*(11), 4015-4022.
- Soni, N., & Prakash, S. (2014 b). Antimicrobial and mosquitocidal activity of microbial synthesized silver nanoparticles. *Parasitology research*, 1-8.
- Soni, N., & Prakash, S. (2014c). Microbial synthesis of spherical nanosilver and nanogold for mosquito control. *Annals of Microbiology*, *64*(3), 1099-1111.
- Soni, N., & Prakash, S.(2015). Different geometrical AgNPs for vector control and their added value of antibacterial activity. Journal of Parasitology. Photon 105,232-243.